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Coated turning insert

The present invention relates to a coated cutting tool (cemented carbide insert) particularly useful for wet turning of toughness demanding stainless steels components like square bars, flanges and tubes, with raw surfaces such as cast skin, forged skin, hot or cold rolled skin or pre-machined surfaces.

When turning stainless steels with cemented carbide tools the cutting edge is worn according to different wear mechanisms, such as adhesive wear, chemical wear, abrasive wear and by edge chipping caused by cracks formed along the cutting edge, the so called comb cracks.

Different cutting conditions require different properties of the cutting insert. For example, when cutting in steels with raw surface zones a coated cemented carbide insert must consist of a tough carbide and have very good coating adhesion. When turning in stainless steels the adhesive wear is generally the dominating wear type.

Measures can be taken to improve the cutting performance with respect to a specific wear type. However, very often such action will have a negative effect on other wear properties.

So far it has been very difficult to improve all tool properties simultaneously. Commercial cemented carbide grades have therefore been optimised with respect to one or few of the wear types and hence to specific application areas.

Swedish patent application 9503056-5 discloses a coated cutting insert particularly useful for turning in hot and cold forged low alloyed steel components. The inserts is characterised by a cemented carbide substrate consisting of Co-WC and cubic carbides having a 15-35 µm thick surface zone depleted from cubic carbides, a coating including a layer of $TiC_xN_yO_z$ with columnar grains, a layer of smooth, fine grained κ-Al_2O_3, and preferably an outer layer of TiN.

Swedish patent application 9504304-8 discloses a coated cutting insert particularly useful for wet and dry milling of low and medium alloyed steels. The insert is characterised by a cemented carbide substrate consisting of Co-WC and cubic carbides, a coating including a layer of $TiC_xN_yO_z$ with columnar grains, a

layer of smooth, fine grained κ-Al_2O_3 and preferably an outer layer of TiN.

It has now been found that combinations of the substrates and coatings described in the above patent applications give rise to excellent cutting performance in stainless steels turning. A cemented carbide substrate with a cubic carbide depleted surface zone combined with a coating in accordance with patent application, 9503056-5, has been found to be especially suitable for high speed turning in easy stainless steel, such as turning of machineability improved 304L, In more difficult work piece materials such as 316-Ti and in operations with a high degree of thermal cycling such as turning of square bars a straight WC-Co substrate of the type described in patent application 9504304-8 has been found the most suitable.

A turning tool insert according to the invention useful for turning of steel consists of a cemented carbide substrate with a highly W-alloyed binder phase and with a well balanced chemical composition and grain size of the WC, a columnar $TiC_xN_yO_z$-layer, a κ-Al_2O_3-layer, a TiN-layer and optionally followed by smoothening the cutting edges by brushing the edges with e.g. a SiC based brush. The substrate has a composition 5-15 wt-% Co, <10 wt-% cubic carbides of the metals from groups IVb, Vb, VIB of the periodic table of elements preferably Ti, Ta and/or Nb and balance of WC.

The cobalt binder phase is highly alloyed with W. The content of W in the binder phase can be expressed as the CW-ratio= M_s / (wt% Co · 0.0161), where M_s is the measured saturation magnetisation of the cemented carbide substrate and wt% Co is the weight percentage of Co in the cemented carbide. The CW-value is a function of the W content in the Co binder phase. A low CW-value corresponds to a high W-content in the binder phase. According to the present invention improved cutting performance is achieved if the cemented carbide substrate has a CW-ratio of 0.76-0.93.

In a preferred embodiment a turning tool insert optimised for difficult stainless steel turning is provided with a cemented carbide substrate with a composition of 6-15 wt% Co, preferably 9-12 wt% Co, most preferably 10-11 wt% Co, 0.2-1.8 wt% cubic carbides, preferably 0.4-1.8 wt% cubic carbides, most preferably

0.5-1.7 wt% cubic carbides of the metals Ta, Nb and Ti and balance WC. The cemented carbide may also contain other carbides from elements from group IVb, Vb or VIb of the periodic table. The content of Ti is preferably on a level corresponding to a technical impurity. The preferred average grain size of the WC depend on the binder phase content. At the preferred composition of 10-11 wt-% Co, the preferred grain size is 1.5-2 µm, most preferably about 1.7 µm. The CW-ratio shall be 0.78-0.93, preferably 0.80-0.91, and most preferably 0.82-0.90. The cemented carbide may contain small amounts, <1 volume %, of η-phase (M_6C), without any detrimental effect. From the CW-value it follows that no free graphite is allowed in the cemented carbide substrate according to the present embodiment.

In another preferred embodiment optimised for machining easy stainless steel, such as machineability improved 304L consists of: a cemented carbide substrate of a composition 5-11 preferably 5-8, most preferably 6.5-8, wt-% Co, 2-10, preferably 4-7.5, most preferably 5-7 wt-% cubic carbides of the metals from groups IVb, Vb, VIB of the periodic table of elements preferably Ti, Ta and/or Nb and balance of WC. The grain size of the WC is in the range of about 2 µm. The cobalt binder phase is highly alloyed with W with a CW-ratio of 0.76-0.92, preferably 0.80-0.90. The cemented carbide substrate may contain small amounts, <1 volume-%, of η-phase (M_6C), with out any detrimental effect. Preferably, an about 15-35 µm thick surface zone depleted of cubic carbides and often enriched in binder phase can be present according to prior art such as disclosed in US 4,610,931. In this case the cemented carbide may contain carbonitride or even nitride.

The coating comprises

- a first (innermost) layer of $TiC_xN_yO_z$ with x+y+z=1, preferably z<0.5, with equiaxed grains with size <0.5 µm and a total thickness <1.5 µm and preferably >0.1 µm.

- a layer of $TiC_xN_yO_z$ with x+y+z=1, preferably with z=0 and x>0.3 and y>0.3, with a thickness of 1-15 µm, preferably 2-8 µm, with columnar grains and with an average diameter of <5 µm, preferably 0.1-2 µm. Most preferred thickness of the $TiC_xN_yO_z$ layer depends on the type of application, 2-5 µm in extremely edgeline-toughness demanding work-piece materials such as Ti-

stabilised stainless steel and 5-8 µm in simpler work-piece materials such as machineability improved 304 type of stainless steel,

- a layer of a smooth, fine-grained (grain size about 0.5-2 µm) Al_2O_3 consisting essentially of the κ-phase. However, the layer may contain small amounts, 1-3 vol-%, of the θ- or the α-phases as determined by XRD-measurement. The Al_2O_3-layer has a thickness of 0.5-6 µm, preferably 0.5-3 µm, and most preferably 0.5-2 µm. Preferably, this Al_2O_3-layer is followed by a further layer (<1 µm, preferably 0.1-0.5 µm thick) of TiN, but the Al_2O_3 layer can be the outermost layer. This outermost layer, Al_2O_3 or TiN, has a surface roughness R_{max}<0.4 µm over a length of 10 µm. The TiN-layer, if present, is preferably removed along the cutting edge.

According to the method of the invention a WC-Co-based cemented carbide substrate is made with a highly W-alloyed binder phase with a CW-ratio according to above and a content of cubic carbide according to above and a WC grain size according to above, a first (innermost) layer of $TiC_xN_yO_z$ with x+y+z=1, preferably z<0.5, with a thickness of < 1.5 µm, and with equiaxed grains with size <0.5 µm using known CVD-methods.

- a layer of $TiC_xN_yO_z$ x+y+z=1, preferably with z=0 and x >0.3 and y >0.3, with a thickness of 1-13 µm, preferably 2-8 µm, with columnar grains and with an average diameter of <5 µm, preferably <2 µm, using preferably MTCVD-technique (using acetonitrile as the carbon and nitrogen source for forming the layer in the temperature range of 700-900 °C). The exact conditions, however, depend to a certain extent on the design of the equipment used.

- a smooth Al_2O_3-layer essentially consisting of κ-Al_2O_3 is deposited under conditions disclosed in e.g. EP-A-523 021. The Al_2O_3 layer has a thickness of 0.5-6 µm, preferably 0.5-3 µm, and most preferably 0.5-2 µm. Preferably, a further layer (<1 µm, preferably 0.1-0.5 µm thick) of TiN is deposited, but the Al_2O_3 layer can be the outermost layer. This outermost layer, Al_2O_3 or TiN, has a surface roughness R_{max}<0.4 µm over a length of 10 µm. The smooth coating surface can be obtained by a gentle wet-blasting the coating surface with fine grained (400-150 mesh) alumina powder or by brushing (preferably used when TiN top coating is present) the edges with brushes based on SiC as

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disclosed in Swedish patent application 9402543-4. The TiN-layer, if present, is preferably removed along the cutting edge.

Example 1

A. A cemented carbide turning tool insert in style CNMG120408-MM with the composition 10.5 wt-% Co, 1.16 wt-% Ta, 0.28 wt-% Nb and balance WC, with a binder phase highly alloyed with W corresponding to a CW-ratio of 0.87, was coated with an innermost 0.5 µm equiaxed TiCN-layer with a high nitrogen content, corresponding to an estimated C/N ratio of 0.05, followed by a 4.3 µm thick layer of columnar TiCN deposited using MT-CVD technique. In subsequent steps during the same coating process a 1.1 µm layer of Al_2O_3 consisting of pure κ-phase according to procedure disclosed in EP-A-523 021. A thin, 0.5 µm, TiN layer was deposited, during the same cycle, on top of the Al_2O_3-layer. The coated insert was brushed by a SiC containing nylon straw brush after coating, removing the outer TiN layer on the edge.

B. A cemented carbide turning tool insert in style CNMG120408-MM with the composition of 7.5 wt-% Co, 1.8 wt-% TiC, 3.0 wt-% TaC, 0.4 wt-% NbC, balance WC and a CW-ratio of 0.88. The cemented carbide had a surface zone, about 25 µm thick, depleted from cubic carbides. The insert was coated with an innermost 0.5 µm equiaxed TiCN-layer with a high nitrogen content, corresponding to an estimated C/N ratio of 0.05, followed by a 7.2 µm thick layer of columnar TiCN deposited using MT-CVD technique. In subsequent steps during the same coating process a 1.2 µm layer of Al_2O_3 consisting of pure κ-phase according to procedure disclosed in EP-A-523 021. A thin, 0.5 µm, TiN layer was deposited, during the same cycle, on top of the Al_2O_3-layer. The coated insert was brushed by a SiC containing nylon straw brush after coating, removing the outer TiN layer on the edge.

C. A competitive cemented carbide turning tool insert in style CNMG120408 from an external leading cemented carbide producer was selected for comparison in a turning test. The carbide had a composition of 9.0 wt-% Co, 0.2 wt-% TiC, 1.7 wt-% TaC, 0.2 wt-% NbC, balance WC and a CW-ratio of 0.90. The insert had a coating consisting of 1.0 µm TiC, 0.8 µm TiN, 1.0 µm TiC and, outermost,

0.8 µm TiN. Examination in light optical microscope revealed no edge treatment subsequent to coating.

D. A competitive cemented carbide turning tool insert in style CNMG120408 from an external leading cemented carbide producer was selected for comparison in a turning test. The cemented carbide had a composition of 5.9 wt-% Co, 3.1 wt-% TiC, 5.6 wt-% TaC, 0.1 wt-% NbC, balance WC and a CW-ratio of 0.95. The cemented carbide had a surface zone, about 30 µm thick, which was enriched in Co content. The insert had a coating consisting of 5.3 µm TiC, 3.6 µm TiCN, outermost, 2.0 µm TiN. Examination in light optical microscope revealed no edge treatment subsequent to coating.

E. A competitive cemented carbide turning tool insert in style CNMG120408 from an external leading cemented carbide producer was selected for comparison in a turning test. The carbide had a composition of 8.9 wt-% Co, balance WC and a CW-ratio of 0.84. The insert had a coating consisting of 1.9 µm TiC, 1.2 µm TiN, 1.5 µm Al_2O_3 laminated with 3 0.1 µm tick layers of TiN and, outermost, 0.8 µm TiN. Examination in light optical microscope revealed no edge treatment subsequent to coating.

F. A competitive cemented carbide turning tool insert in style CNMG120408 from an external leading cemented carbide producer was selected for comparison in a turning test. The carbide had a composition of 5.4 wt-% Co, 2.7 wt-% TiC, 3.5 wt-% TaC, 2.3 wt-% NbC, balance WC and a CW-ratio of 0.94. The cemented carbide had a surface zone, about 40 µm thick, which was enriched in Co content. The insert had a coating consisting of 5.3 µm TiC, 3.6 µm TiCN, outermost, 2.0 µm TiN. Examination in light optical microscope revealed no edge treatment subsequent to coating.

Inserts from A, B, C, D, E and F were compared in facing of a bar, diameter 180, with two, opposite, flat sides (thickness 120 mm) in 4LR60 material. Feed 0.25 mm/rev, speed 180 m/min and depth of cut 2.0 mm.

The wear mechanism in this test is chipping of the edge. The inserts with gradient substrates (B, E and F) looked good after three cuts but broke suddenly after about four.

Insert	Number of cuts
A (acc. to invent.)	15
B (acc. to invent.)	5
C (external grade)	9
D (external grade)	9
E (external grade)	4
F (external grade)	4

Example 2

Inserts A, and B from above were selected for a turning test, longitudinal and facing in machineability improved AISI304L stainless steel.

Cutting speed was 250 m/min, feed 0.3 mm/rev and depth of cut 2 mm. Cutting time 1 minute/cycle.

The wear mechanism was plastic deformation.

Insert	Number of cycles
B (acc. to invent.)	7
A (acc. to invent.)	4

Example 3

G. Inserts in geometry TNMG160408-MM with composition and coating according to A above.

H. Inserts in geometry TNMG160408-MM with composition and coating according to B above.

I. Inserts in geometry TNMG160408 with composition and coating according to C above.

The inserts G, H and I were tested in longitudinal, dry, turning of a shaft in duplex stainless steel.

Feed 0.3 mm/rev, speed 140 m/min and depth of cut 2 mm. Total cutting time per component was 12 minutes.

Insert G and I got plastic deformation whereas insert H got some notch wear.

Two edges of insert G were worn out to produce one component whereas one edge of insert H completed one component and four edges were required to finalise one component using insert I.

Insert	Number of edges/component
H (acc. to invent.)	1
G (acc. to invent.)	2
I (external grade)	4

Example 4

Inserts A and E from above were selected for a turning test, mainly facing, in a cover rotorcase made in cast AISI316 stainless steel. The cutting was interrupted due to component design.

Cutting speed was 180 m/min, feed 0.2 mm/rev and depth of cut 0-2 mm (irregular shape of casting). Cutting time 10.5 minutes/component.

The wear mechanism was a combination of edge chipping and plastic deformation.

Insert	Number of components
A (acc. to invent.)	2
E (external grade)	1

Example 5

J. Inserts in geometry CNMG160612-MR with composition and coating according to B above.

K. A competitive cemented carbide turning tool insert in style CNMG160612 from an external leading cemented carbide producer was selected for comparison in a turning test. The carbide had a composition of 6.3 wt-% Co, 2.7 wt-% TiC, 3.4 wt-% TaC, 2.1 wt-% NbC, balance WC and a CW-ratio of 0.89. The cemented carbide had a surface zone, about 20 μm thick, depleted from cubic carbides. The insert had a coating consisting of 0.1 μm TiN, 6.0 μm columnar TiCN, 1.5 μm multicoating, 1.4 μm Al_2O_3 and outermost, 0.6 μm TiN. Examination in light optical microscope revealed no edge treatment subsequent to coating.

Inserts J and K were selected for a turning test. Longitudinal and facing of cast valve component in AISI316L stainless steel. Cutting speed was 110 m/min, feed 0.25/0.3 mm/rev and depth of cut 1.25 mm. Cutting time was 2.8 minutes/component. Eight edges were tested per insert type.

The wear was chipping of the edge for insert J and uneven flank wear for insert K.

Insert	Average number of components
J (acc. to invent.)	6.8
K (external grade)	4.4

Example 6

Inserts according to A, B, C and D were selected for a turning test. Internal turning of AISI304 stainless steel valve substrate. Cutting speed was 130 m/min and feed 0.4 mm/rev. The stability was poor due to the boring bar.

The wear was chipping of the edge for inserts D and B whereas inserts A and C got plastic deformation.

Insert	Number of components
A (acc. to invent.)	9
D (external grade)	7
C (external grade)	5
B(acc. to invent.)	2

Example 7

Inserts A and C from above were selected for a turning test, roughing of a square bar in AISI316Ti stainless steel. The cutting was interrupted due to component design.

Cutting speed was 142 m/min, feed 0.2 mm/rev, depth of cut 4 mm. and cutting time 0.13 minutes/component.

The wear was chipping of the edge.

Insert	Number of components
A (acc. to invent.)	25
C (external grade)	15

Claims

1. A cutting tool insert for turning of steel comprising a cemented carbide body and a coating c h a r a c t e r i s e d in that said cemented carbide body consists of WC, 5-15 wt-% Co and <10 wt-% cubic carbides of Ti, Ta and/or Nb and a highly W-alloyed binder phase with a CW-ratio of 0.76-0.93 and in that said coating comprises

- a first (innermost) layer of $TiC_xN_yO_z$ with a thickness of <1.5 µm, and with equiaxed grains with size <0.5 µm
- a layer of $TiC_xN_yO_z$ with a thickness of 1-15 µm with columnar grains with an average diameter of <5 µm
- an outer layer of a smooth, fine-grained (0.5-2 µm) κ-Al_2O_3-layer with a thickness of 0.5-6 µm.

2. Cutting tool insert according to the previous claim c h a r a c t e r i s e d in that said cemented carbide body consists of WC, 6-15, preferably 9-12, wt-% Co and 0.2-1.8 wt-% cubic carbides of Ti, Ta and/or Nb and a highly W-alloyed binder phase with a CW-ratio of 0.78-0.93, preferably 0.80-0.91 and in that said coating comprises

- a first (innermost) layer of $TiC_xN_yO_z$ with a thickness of <1.5 µm, and with equiaxed grains with size <0.5 µm
- a layer of $TiC_xN_yO_z$ with a thickness of 2-5 µm with columnar grains with an average diameter of <5 µm
- an outer layer of a smooth, fine-grained (0.5-2 µm) κ-Al_2O_3-layer with a thickness of 0.5-6 µm.

3. Cutting tool insert according to claim 1 c h a r a c t e r i s e d in that said cemented carbide body consists of WC, 5-11, preferably 5-8, wt-% Co and 4-7.5 wt-% cubic carbides of Ti, Ta and/or Nb and a highly W-alloyed binder phase with a CW-ratio of 0.76-0.92, preferably 0.80-0.90 and in that said coating comprises

- a first (innermost) layer of $TiC_xN_yO_z$ with a thickness of <1.5 µm, and with equiaxed grains with size <0.5 µm
- a layer of $TiC_xN_yO_z$ with a thickness of 5-8 µm with columnar grains with an average diameter of <5 µm
- an outer layer of a smooth, fine-grained (0.5-2 µm) κ-Al_2O_3-layer with a thickness of 0.5-6 µm.

4. Cutting insert according to claim 3 c h a r a c t e r i s e d in that the cemented carbide body has a surface zone 15-35 µm thick depleted from cubic carbides.

5. Cutting insert according to any of the preceding claims c h a r a c t e r i s e d in that the outermost layer is a thin 0.1-1 µm TiN-layer.

6. Cutting insert according to claim 5 c h a r a c t e r i s e d in that the outermost TiN-layer has been removed along the cutting edge.

Abstract

The present invention discloses a coated turning insert particularly useful for turning in stainless steel. The insert is characterised by WC-Co-based cemented carbide substrate having a highly W-allcyed Co-binder phase and a coating including an innermost layer of $TiC_xN_yO_z$ with columnar grains and a top layer of TiN and an inner layer of fine grained κ-Al_2O_3.